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Soundscape psychophysics in place

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Based on exposure-response curves for annoyance, immission values less than 55 dB LAeq,16h is typically required for one type of traffic noise at a time. Such energetic time-averages do neither convey information on sound components, nor on soundscape structure and dynamics. Due to the ecological fallacy, population-based annoyance curves are inappropriate for predicting mitigation efficiency and for creating good soundscapes. Thus, soundscape psychophysics has to be put in place, both indoors and outdoors. Research showed that: (i) Sound level overestimates mitigation effects on the perceived soundscapes outdoors with and without barriers and indoors with open and closed windows. (ii) The mix of positive-and adverse characteristics of soundscapes makes residents accept higher sound levels at outdoor (<50 dB) than indoor places (30-40 dB). (iii) A mix predominated by nature and human-activity sounds, over mechanical sounds, is critical for good soundscape quality, which is measured in metric space as regards pleasant-unpleasant, exciting-boring, eventful-uneventful, and chaotic-tranquil. (*iv)* The Soundscape Walk is launched in which a panel assesses the quality of soundscapes in residential areas and soundscape places are classified according to total perceptual valuations.

1 INTRODUCTION

Health-supportive soundscapes would have to be accomplished by a combination of behavioral changes (choices and decisions), remedial actions against noise and creative city planning of soundscapes, particularly in urban renewal [1, 2, 3]. It is not enough to protect and prevent against noise pollution. It is also necessary to promote and support health and wellbeing [4]. Therefore, a main research goal is to provide methods by which it will be possible to characterize soundscape quality and not only sound levels of single sources including propagation paths. The long-term goal must be to introduce soundscape design in city planning.

Schafer [5] defined soundscapes as the sound variations in space and time caused by the topography of the built-up city and its different sound sources. It is however fruitful to distinguish between the perceived soundscape and the acoustic soundscape. Perceived soundscapes are described with the aid of human listeners whereas acoustic soundscapes are described with the aid of physical measuring instruments [6]. The present research is concerned with the perceived soundscapes and their link to the acoustic soundscapes.

The major challenges in soundscape research is to find out how perceived soundscapes contributes to the meaning of places and to develop methods for designing and measuring the perceived soundscape. Clearly, the perceived soundscape contributes to the meaning of

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places like "quiet area", "courtyard" or "living room" [7]. A main goal of the present research is therefore to put soundscape psychophysics in place by the aid of four application examples. The first shows how (perceived) loudness of soundscapes is affected by noise mitigation measures. The second demonstrates how the meaning of place affects our criteria for good soundscape quality. The third delivers an empirically based measurement model for soundscape quality. The fourth launches the Soundscape Walk for measuring soundscape quality in places.

2 FOUR APPLICATION EXAMPLES OF SOUNDSCAPE PSYCHOPHYSICS

2.1 Noise Mitigation Effects on Soundscape Perception

To improve soundscapes, current practice is to reduce the sound level of adverse sounds, primarily transportation and industrial noise. Thus, conventional remedial actions include noise barriers, shielding buildings, whispering asphalt, traffic-volume or traffic-speed reductions as well as sound insulation and active noise control [2]. Even if these actions reduce A-weighted sound level equally much, it cannot be assumed that the effect on the perceived soundscape will be the same. Obviously, new prerequisites for sound propagation, reflection and absorption will apply. Selected method of mitigation will be tied to specific changes in spectral and temporal properties of the noise. For instance, noise barriers will increase the relative proportion of low-frequency content and decrease the variability of traffic noise, whereas traffic volume reductions may not result in such changes. Three explanations of why our research shows that noise mitigation affects soundscape quality is given below.

(1) The perceived character of noise is related to its spectral and temporal properties. It is well known that noise annoyance is influenced by the character of the noise [8]. From our listening experiments, we know that (perceived) loudness and annoyance are affected by the relative proportion of low-frequency content of traffic noise [9,10]. Therefore, a plausible hypothesis is that noise barriers and similar shielding are less efficient in reducing annoyance than other remedial actions that leave the spectrum unchanged (e.g., decreased traffic volume). This hypothesis has partly been confirmed in our psychoacoustic experiments on road-traffic noise annoyance [11]. If heard behind a 4.6 m high roadside barrier the traffic noise is *more* annoying than road traffic noise of the same sound level without the noise barrier. This result was not confirmed for a lower barrier (3.4 m) of different construction, presumably because it had less influence on the relative proportion of low-frequency content than the 4.6 m barrier.

(2) Detection and identification of traffic noise is related to its spectral and temporal properties. The mere presence of traffic noise even at levels below the background sound level, has a negative effect on soundscape perception. We found support for this in our studies involving listening walks in residential areas [12,13]. Resident's soundscapes indoors with closed windows at traffic-noise exposed sides of apartments were found to be louder and more annoying than could be expected from the measured overall sound level. A probable main reason is that traffic noise was still audible through the windows. The soundscape at the shielded side of the apartments was considerably better, although the difference in overall sound level between exposed and shielded sides was only 5 dB (with closed windows), see Figure 1.

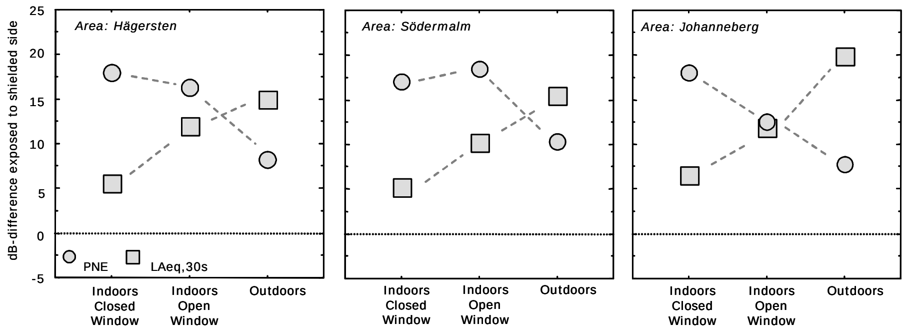

Figure 1. dB-differences in perceived loudness (PNE) and dB-differences in sound level (LAeq,30s) compared for pairs of soundscapes at exposed and shielded sides of buildings.

(3) The ability of traffic noise to mask positive sounds in the soundscape is related to the temporal structure and the spectral content of the noise. The underlying processes may be of various kinds. For example, due to "energetic" masking, continuous road-traffic noise may completely mask bird song, and thereby eliminate a potentially positive component of the soundscape. "Informational" masking may lead to identification errors. For example, road-traffic noise may be attributed to an existing fountain generating pleasant water sounds, and traffic noise may, thereby, be perceived as a positive component of the soundscape. We are currently determining, experimentally, the effects of various noise mitigation methods on soundscape perception primarily focusing on positive sound components.

A general conclusion of our research is that the sound level measure overestimates the mitigation effects on the perceived soundscapes outdoors with and without noise barriers as well as indoors with open and closed windows.

2.2 The meaning of place affects residents' criteria for good soundscape quality

One interesting feature of complex perception is that it is possible simultaneously to have positive and negative perceptions. Soundscapes are examples of such complex perceptions. It is easy to imagine that soundscapes can be annoying and pleasant at the same time, because we hear singing birds or rustling leaves in between occasional car passages. Our perception also depends on our activities, for example, having a conversation or relaxing [2] and on our expectations on the place (living room or park). Thus, it is natural that the setting or place in which the soundscape is embedded generate requirements which in turn influences how we perceive or evaluate soundscapes. These influences of place on perceived soundscapes may be viewed as context effects; the soundscape means something special in relation to the psychology of the place.

The general idea is well illustrated with results from our listening walks in residential areas. The psychoacoustic data from the soundscape walks of 106 residents in four residential areas of two Swedish cities produced 12-attribure profiles of 965 residential soundscapes in various places. The attributes had both positive and negative connotations and therefore we decided to define acceptable soundscape quality in terms of the sound level at which the attributes annoyance and soothing characterized the soundscape equally well. Figure 2 shows soundscape-attribute match plotted against 5-dB-band sound level category expressed as LAeq,30s. The increasing curves refer to annoyance and the decreasing curves to soothing. From right to left the diagrams show that acceptable soundscape quality is reached in the 50 dB category if outdoors, in the 40 dB category if indoors with open window and in the 30 dB category in indoors with closed window. Contextually, we expect and accept that the

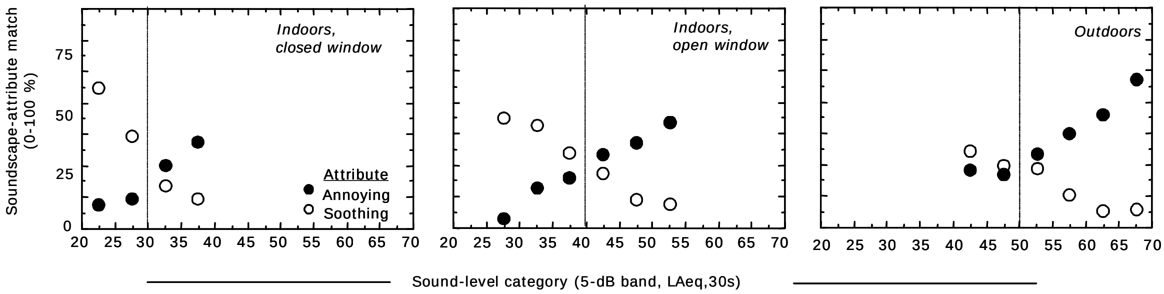

Figure 2. Perceived attribute match for positive (soothing) and adverse (annoying) attributes as a function of overall sound level (LAeq,30s).

soundscapes have the highest sound level outdoors, lower sound level indoors with open window and the least sound level indoors with closed window.

A general conclusion of our research is that the mix of positive and adverse characteristics of soundscapes makes residents' accept sound levels outdoors up to 50 dB, but requires that the indoor soundscapes should not surpass 40 dB and should be as low as 30 dB with windows closed. These sound levels are in agreement with the WHO guideline values [2], which also refer to place and conditions with window open or closed.

2.3 A Measurement Model for Soundscape Quality in Place

Soundscapes typically contain several sounds which occur simultaneously or separately in time. These component sounds may be positive (e.g., sounds from nature) or adverse (e.g., traffic noise). Despite of this soundscape complexity, human listeners can meaningfully evaluate the *overall* soundscape. For example, the soundscape in a quiet park is more pleasant, more soothing, less annoying, and less stressful than the soundscape of a sidewalk close to a busy road. A research question of great importance is if it is possible to formulate a model by which all possible attributes of soundscapes may be integrated (pleasant, eventful, annoying, etc.) to a small number of fundamental dimensions of soundscape perception. Such a model would bring soundscape research a step forward, because future research would be guided on what to measure (method) and what to look for (theory).

We conducted listening experiments with 100 participants [14]. These evaluated 30-s recordings of 50 different soundscapes, carefully chosen to represent a wide range of possible *outdoor* soundscapes. The listener evaluated the soundscapes with the help of 116 perceptual-emotional attribute scales. We wanted to represent the 116 attributes by a small number of orthogonal soundscape dimensions and therefore we chose to conduct a principal components analyses (PCA) on coefficients of correlation among all pairs of the soundscapes. The first two components was found to explain 50% and 18% of the total variance. The first component was labeled "Pleasantness" because the three attributes with the highest absolute loadings in this component were *pleasant* (0.96), *unpleasant* (-0.96), and *appealing* (0.96). The second component was labeled "Eventfulness" because the three attributes with the highest absolute loadings on this component was *eventful* (0.90), *lively* (0.86), and *uneventful* (-0.84). [Remaining components explained at most 6 % of the total variance.]

Figure 1 shows a factor score plot of the two first components "Pleasantness" and "Eventfulness". Each circle represents one soundscape's location in the space defined by the first two components. Attributes best related to these two fundamental dimensions are indicated in the figure. The results show that an "exciting" soundscape is pleasant and eventful, whereas a "quiet" soundscape is pleasant and uneventful. A "chaotic" soundscape is

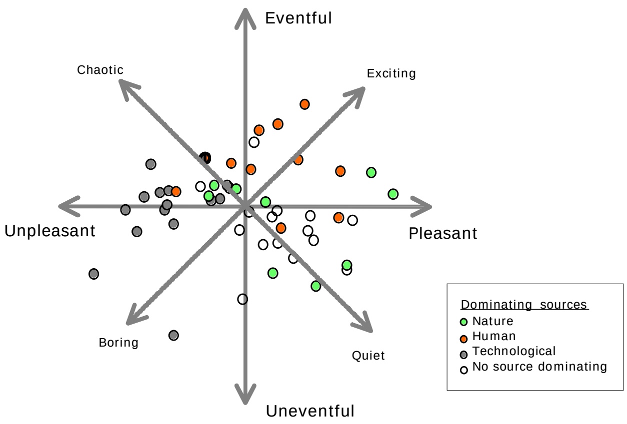

Figure 3: Model of perceived soundscape quality derived from a PCA of 116 attribute-scales of 50 outdoor soundscapes (=circles). Factor scores were used for locating the soundscapes in the space of the two first principal components ("Pleasantness" and "Eventfulness"). Legend gives type of dominating source in soundscape (Adopted from [14].)

unpleasant and eventful, whereas a "boring" soundscape is unpleasant and uneventful. This measurement model for soundscapes is compatible with Russel's "circumplex" model of human emotions [15-17].

The colors of the circles in Figure 3 indicate which type of source that dominated in the particular soundscape. The general pattern of colors in Figure 3 may be summarized as follows: Soundscapes dominated by technological sounds were unpleasant (grey circles located to the left in the figure), whereas nature sounds were pleasant (green circles located to the right in the figure). Less obvious was the finding that soundscapes dominated by human sounds were more eventful than soundscapes without human sounds (orange circles located at the top in the figure). These results suggest *i.a*. that the following strategies might help to improve the soundscapes: First, in order to achieve pleasant soundscapes, nature sounds should be promoted and technological sounds abated. Fountains and vegetation attracting birds and generating sounds of wind may be used for increasing the number of nature sounds; and various noise mitigation methods may be used for abating the technological sounds. Second, it is important to decide if the "pleasant" soundscape should be "eventful" or "uneventful". In the former case, the soundscape is perceived as "exciting", in the latter case as "quiet" (see Fig. 3). In order to create an "exciting" soundscape, sounds from humans should be promoted, for example, by cafeterias and playgrounds. Conversely, if a "quiet" soundscape is to be planned (e.g., a therapeutic garden), sounds from humans should be avoided.

Among the 50 soundscapes, eventfulness was perceived to increase with increases in overall sound level, but this relationship was found to be weaker than for pleasantness (Pearson's r=0.4 for eventfulness and -0.7 for pleasantness). Other acoustic measures, such as variation in time and frequency content, show weak associations with eventfulness. However, the presence or absence of people explained a large part of the variation in eventfulness as compared to acoustic measures (LAeq,30s, N_{10}, N_{10}-N_{90}, or LCeq-LAeq). Obviously, the sounds of people makes soundscapes eventful, for example in quiet areas or noise-dominated environments where other sounds are masked. This interpretation is supported by environmental psychological research, which shows that persons become activated, physiologically, psychologically, and socially, when other persons are around.

The present soundscape research clearly show that it is necessary to include information content or meaning in the measurement model. That is, information on the specific type of identifiable sounds attributable to certain sources. A measurement model restricted to acoustic properties would be less fruitful. This research also shows that the concept of pleasant soundscape is ambiguous. It may involve both eventful and stimulating soundscapes or both uneventful and soothing soundscapes. The critical difference is whether or not activities of people may be heard. It is therefore wise to include meeting places for people in the soundscape designs, for example, children's playgrounds or small cafés. Conversely, soothing places for psychological restoration would require outdoor spaces secluded from various activities of people. In both cases, good soundscapes are created by the positive nature sounds provided prominent technological sounds are avoided.

In conclusion, a mix with predominately nature and human-activity sounds, over mechanical sounds, was found to be critical for good soundscape quality in places. Soundscape quality was successfully measured in metric space defined by the following axes separated by 45 degrees: pleasant-unpleasant, exciting-boring, eventful-uneventful, and chaotic-tranquil.

2.4 The Soundscape Walk

The Soundscape Walk is a method by which soundscape quality may be measured in places intended to be quiet and/or restorative. The walking tour is defined by the number of places which should be visited. At each place the soundscape quality should be assessed by the selected panel according to a structured protocol. Thus far, we have developed the Soundscape Walk for residential areas in places outdoors and indoors. The structured response protocol is currently being validated in different urban areas in Sweden. The method provides a way to measure soundscape quality in situations where acoustic information (e.g., sound level) is less relevant, such as potentially supportive soundscapes in areas with moderate or low noise exposures.

3 CONCLUSIONS

In the Swedish multi-disciplinary research programme "Soundscape Support to Health", we have developed several methods for measuring the perceived soundscape. The methods include listening tests in the virtual-reality laboratory, listening walks in the field, and questionnaire studies targeted on the soundscape. The research has focused on soundscapes in residential areas or in natural environments in urban and suburban areas where people choose to spend their time in specific places. We have been able to identify fundamental perceptual dimensions of soundscapes (pleasantness and eventfulness), to link these features to important acoustical and informational properties of soundscapes (e.g., type of source), and to determine the effect of noise mitigation on soundscape perception. Main findings were:

(a) Mitigation efficiency expressed in sound level reduction of barriers and facades may largely overestimate the efficiency actually obtained in terms of perceptual mitigation. This is also true for open or closed windows.
(b) The traffic noise in soundscapes must be reduced below 50 dBA; only then is there a chance to create good soundscape quality outdoors in urban residential (and recreational) areas.
(c) A measurement model for soundscape quality has been developed and is ready for use in the Soundscape Walk. Soundscape quality is measured and classified as Pleasantness and Eventfulness. Sounds from nature predominate in the pleasant soundscape, and in the eventful soundscape sounds from humans predominate.

Based on these findings, new tools for 'green labeling' of soundscapes have been developed. Presently, the tool consists of a check-list of factors that contribute to or diminish overall soundscape quality (e.g., presence/absence of nature sounds, audibility of traffic noise, presence/absence of human sounds, overall sound level, etc). A method for integrating these factors into a measure of overall soundscape quality is included in the toolbox. In the future, a neural network model will be developed for predicting perceived soundscape quality [18,19].

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